Quantifying Nutrient and Sediment Loads during Spring Runoff in the Missisquoi River Basin

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Quantifying Nutrient and Sediment Loads during Spring Runoff in the Missisquoi River Basin

The University of Vermont
College of Engineering and Mathematical Sciences
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Baxter Miatke

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Andrew Schroth Ph. D., Donna Rizzo Ph.D., Arne Bombies Ph. D.

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Abstract

The timing and magnitude of the spring runoff period and associated high nutrient loads, driven by snowmelt and rain, has recently been suggested as a critical driver of harmful summer algal blooms in receiving waters. This project focused on characterizing nutrient and sediment dynamics during the spring runoff period in the Missisquoi River Basin and quantifying loads during this understudied time period. Analysis focused on total phosphorus (TP), total nitrogen (TN), and total suspended solids (TSS). Phosphorus was critical, as it has significant downstream impacts, such as lake eutrophication and harmful algal blooms (HAB’s). Nutrient and sediment loads were quantified during the spring runoff period (March-May 2014) at 3 sites on the Missisquoi River and an additional site on the highly agricultural Hungerford Brook tributary. A linear regression model and an R script statistical software package that used a weighted regression on time, discharge, and season (WRTDS) were both used to quantify load estimations. The spring 2014 data collection effort leveraged existing (2012-2014) summer data from the Vermont EPSCoR (Experimental Program to Stimulate Competitive Research) program on Research on Adaptation to Climate Change (RACC) that has monitored the same sites during the summer time period, which allows us to quantify inter-annual and seasonal variability of the loading of these constituents. The spring 2014 data were compared with the existing (2012-2013) summer data to effectively analyze the seasonal trends and spatial patterns within the Missisquoi Basin during the spring runoff with respect to load estimates. It was found that the spring runoff period contributes a large amount of discharge and therefore nutrient and sediment loads to the Missisquoi River. The addition of the spring data provided a better seasonal analysis of nutrient loading trends for the Missisquoi River watershed. Load estimates varied both spatially and seasonally indicating the inter-annual variability in spring snowmelt and runoff that likely impact Lake Champlain water quality and harmful algal bloom dynamics.
1. Introduction

Vermont EPSCoR is currently performing research on the adaptation to the climate change (RACC). One of the overarching questions within the RACC program is “What is the relative importance of in-lake processes (internal) versus out-of-lake (external) processes in driving harmful algae blooms within Lake Champlain?” (EPSCoR 2015) In order to answer this question, nutrient loads are studied by RACC researchers during the summer and fall from June to October focusing on the harmful algae blooms that occur in Lake Champlain. “The nutrient load refers to the total amount of nitrogen or phosphorus entering the water during a given time, such as "tons of nitrogen per year” (DNR 2015). This is different than the concentration, which is the mass defined in a volume of fluid such as water; i.e. milligrams per liter. Nutrient loads are more effective than concentration data for quantifying constituent dynamics at different spatial locations along the river over time, because loads take into account both time and discharge in addition to concentration. The current work done by RACC on nutrient loading to date does not adequately capture the critical spring runoff period, only summer and fall. It was the aim of this project to work with RACC and Vermont EPSCoR to analyze spring runoff nutrient and sediment loading to better understand the seasonal controls on nutrient and sediment loading to the lake. The overall objective was to describe the critical nutrient input parameters to Missisquoi Bay, enhance the process-based understanding of nutrient loading to the bay in both time (seasons) and space (location), and re-evaluate the methods used currently for load estimations.
2. Background

Snowmelt and heavy spring rains have been suggested to be critical drivers of the severity of summer harmful algal blooms (HABs) (Daloglu 2012). The runoff in the winter and spring promotes high concentrations and loads of macronutrients and sediment in stream waters, which are then delivered to receiving waters where the nutrients have potential to generate HABs as waters warm in the summer. In the northeastern U.S., the spring time period is specifically important for quantification of nutrient loading because of the high number of extreme storm events during this season, as well as high flows generated by melting snowpack. In a phosphorus load study in Lake Erie, it was found that the frequency of extreme storm events (defined as above the 85th percentile) since 1970 has been greater in the spring than in the fall. This same study showed that the frequency of such events has increased more dramatically during both spring and fall fertilizer seasons over the past decade, demonstrating the importance and need of spring runoff data when calculating nutrient loads (Daloglu 2012). The spring runoff season is likely to change significantly due to climate change, possibly causing earlier spring conditions, less snow, and more rain, all of which may have dramatic impacts on the temporal and spatial drivers of springtime nutrient loading. However, relatively few estimates of winter and spring nutrient and sediment loads exist to establish historical context. After researching the effects of macronutrient loading from the Missisquoi River during the summer (June to August 2013) with VT EPSCoR and RACC, it was evident that further research on spring runoff was needed.

Rivers make significant contributions to macronutrient (e.g., Phosphorus, Nitrogen) delivery and enrichment of lakes throughout the year. Of the major nutrients, phosphorus is of main concern as it is a limiting nutrient of phytoplankton populations in freshwaters and promotes eutrophication when supplied in excess, however riverine nitrogen is also thought to play an important role in HAB dynamics. In the Lake Champlain Basin, the Missisquoi River is a critical source of phosphorus and nitrogen, which has caused Missisquoi Bay to become eutrophic due to the high phosphorus loading and contamination (Smeltzer 2012). There is currently limited information on how the nutrient load size differs at multiple locations along the river, especially during spring runoff. Estimating these nutrient and sediment loads during
the spring runoff is essential if one wishes to make accurate estimates of the expected nutrient loading for Missisquoi Bay and further use these estimates in predictive models to determine the effects of climate change on nutrient transport and lake water quality.

2.1 Site Description:

The Missisquoi River runs 88 miles through northern Vermont and southern Quebec, and drains to Lake Champlain in Missisquoi Bay (Figure 1). Missisquoi Bay drains 855 square miles of northwestern Vermont and southern Quebec with almost 60% of the drainage area in Vermont. Despite significant phosphorus-load reduction efforts in the Missisquoi River Basin, a large agricultural basin, land-use practices over the past centuries in the watershed have led to a degradation of the water quality in the river and the bay. There are four main sites (Figure 1) along the Missisquoi River where the United States Geological Survey (USGS) has active gauging stations (Table 1). The Swanton and Hungerford Brook sites are located closest to the lake and have historically high concentrations of phosphorus. The site at East Berkshire is in a large agricultural area of Vermont and the site at North Troy is at the headwaters of the river and has the highest elevation. The land-use catchment area data reported in acres and percent (Table 2) for the Missisquoi River Basin were obtained from VT-EPSCoR, and is necessary for normalizing loads to catchment area. This is important for understanding how land use can affect nutrient loading.

Table 1- USGS Station Number, Location, Drainage Area, Datum, and Sampling Threshold

<table>
<thead>
<tr>
<th>Site</th>
<th>Latitude/Longitude</th>
<th>Drainage Area</th>
<th>Datum Gage</th>
<th>Station</th>
<th>Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swanton</td>
<td>44°55'00&quot;N 73°07'44&quot;W</td>
<td>850 sq. miles</td>
<td>105 ft. above</td>
<td>4294000</td>
<td>2 m</td>
</tr>
<tr>
<td>East Berkshire</td>
<td>44°55'06&quot;N 73°03'20&quot;W</td>
<td>18.6 sq. miles</td>
<td>270 ft. above</td>
<td>4293900</td>
<td>2 m</td>
</tr>
<tr>
<td>Hungerford Brook</td>
<td>44°57'36&quot;N 72°41'49&quot;W</td>
<td>479 sq. miles</td>
<td>402.51 ft. above</td>
<td>4293500</td>
<td>4 m</td>
</tr>
<tr>
<td>North Troy</td>
<td>44°58'22&quot;N 72°23'09&quot;W</td>
<td>131 sq. miles</td>
<td>580 ft. above</td>
<td>4293000</td>
<td>3 m</td>
</tr>
</tbody>
</table>
Figure 1-Missisquoi River Watershed Map with USGS Gauge Stations Highlighted: Swanton(1), Hungerford Brook(2), East Berkshire(3), and North Troy(4)
### 3. Methodology

#### 3.1 Nutrient Sampling

Each USGS station had automatic sampling systems (ISCO’s) to collect water samples at both peak and base flows. Each automatic ISCO could take up to 24 water samples in 1 liter bottles. The ISCO program was set to collect samples when the river reached certain stage thresholds as seen in the last column in Table 1. Upon each site visit, the ISCO’s were serviced, which included recording all measurement data, replacing the bottles with acid washed bottles, and fixing any tubing or other malfunctions. Base-flow samples were also collected during site visits and at least once a month to compare to high-flow events. In the winter, the ISCO’s were removed due to ice. They were not installed for spring snowmelt; so grab samples were collected instead using carboys and 1-liter bottles. The methods of Worsfold et. al (2009) were used and modified slightly for snow and ice conditions. When the river was frozen, it was necessary to break the ice to enable sampling the water below. Safety was a concern during snowmelt conditions for site access and grab samples on the icy terrain. These conditions made sites like North Troy especially difficult to sample and is responsible for the limited number of samples from that site. The USGS gauge stations continue measuring flow throughout the year and these discharge data are provisional until approved by USGS, which takes several months due to early spring data validation protocols. Past data from USGS gauge stations shows that a large percentage of the total Missisquoi River discharge in a given year occurs over the period from March to May. Figure 2 shows the hydrograph from the USGS gauge station at Swanton in 2013 and the RACC 2013 sampling efforts. It is important to note that the RACC sampling events are missing some of the peak flows in the spring months.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Catchment Area Acres</th>
<th>Agricultural Acres</th>
<th>Percent Catchment Agricultural</th>
<th>Urban Acres</th>
<th>Percent Catchment Urban</th>
<th>Forested Acres</th>
<th>Percent Catchment Forested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hungerford Brook</td>
<td>11877.07</td>
<td>6742.81</td>
<td>0.568</td>
<td>613.92</td>
<td>0.052</td>
<td>4179.19</td>
<td>0.352</td>
</tr>
<tr>
<td>Missisquoi River at East Berkshire</td>
<td>306047.88</td>
<td>48297.13</td>
<td>0.158</td>
<td>7087.6</td>
<td>0.023</td>
<td>241621.32</td>
<td>0.789</td>
</tr>
<tr>
<td>Missisquoi River at North Troy</td>
<td>85025.54</td>
<td>10150.94</td>
<td>0.119</td>
<td>873.52</td>
<td>0.010</td>
<td>70556.04</td>
<td>0.830</td>
</tr>
<tr>
<td>Missisquoi River at Swanton</td>
<td>544799.70</td>
<td>110249.25</td>
<td>0.202</td>
<td>12362.25</td>
<td>0.023</td>
<td>404447.53</td>
<td>0.742</td>
</tr>
</tbody>
</table>
The sampling schedule for the spring was between March-May (2014) and depended on weather conditions such as high runoff due to higher temperatures. The goal was to sample during the rise and fall of the peak discharge. The sampling events superimposed on the spring 2014 hydrographs for the four sites are shown in Figures 3-6. The automatic ISCO samplers were installed on 6/10/14, which explains the higher sampling frequency after the spring.
Figure 4 - Hungerford Brook hydrograph and sampling events, Spring 2014

Figure 5 - East Berkshire hydrograph and sampling events, Spring 2014
Based on the hydrograph patterns and weather data from the Burlington International Airport (Weather Underground, 2014), the peak spring snowmelt occurred from 3/30/14 to 4/14/14. Rain on snow events occurred from 4/15/14-4/18/14 and spring runoff storm events occurred from 4/19/14-5/1/14.

3.2 Laboratory Methods

The water samples were stored on ice and transported to VT-EPSCoR Johnson State College (JSC) lab within 24 hours of being collected, for testing of soluble reactive phosphorus (SRP), dissolved inorganic nitrogen, ammonium, total phosphorus, and total nitrogen by Saul Blocher. Samples were also transported to VT-EPSCoR Saint Michael's College (SMC) lab and tested for total suspended solids (TSS) by Katie Chang. Samples were also run for SRP analysis at the UVM Rubenstein Eco-System Lab by Baxter Miatke and Braden Rosenberg. This SRP analysis was done during spring 2014 sampling when samples could not be transported to JSC for analysis. Comparison of SRP between labs was performed to check and correct for differences.
3.3 Estimating Loads Methods

Laboratory analyses, measured in concentration (mass/volume), were combined with available discharge data to develop loads (mass/time). Load estimations were first quantified by creating a simple linear regression model and then compared to the statistical modeling software; R Script: EGRET Package that uses the WRTDS method (Hirsch 2010).

3.4 Linear Regression Model

The USGS 15-minute discharge data were first collected for each of the four sites over a select one-year time period and organized in an Excel workbook. The 15-minute discharges were each averaged to use more accurate discharges for the flow during that 15 minute time period. The concentrations of the nutrients were plotted against the discharge corresponding to the time that river sample was collected. A best-fit linear regression model was developed for all points on the concentration vs. discharge graphs and then used to estimate concentrations at every 15 minute discharge value. If the estimated concentration was negative due to regression, it was assumed negligible due to extremely low flow and fixed at 0. The estimated concentration was then multiplied by the discharge to obtain a flux requiring a conversion of 1 ft³/s to 28.317 L/s. This flux is then multiplied by the 15-minute time interval to get a mass per 15-minute flux. All fluxes were then summed over specified time periods to obtain period-specific fluxes (annual, seasonal). All sites were summed between the same dates based on available USGS data. The final flux is represented either as kg/yr or mT/yr even though the exact time period of data from USGS does not span the entire year.

3.5 R Script: EGRET Model, WRTDS Method

R Script is a statistical software tool that has several packages and uses. This project made use of the Exploration and Graphics for RivEr Trends (EGRET) package. The EGRET package performs an analysis of long-term changes in river-water quality and stream flow, including “Weighted Regressions on Time, Discharge, and Season” (WRTDS). The WRTDS method is formulated to allow for maximum flexibility in representing the long-term trends, seasonal components, and discharge-related components of the behavior of the water-quality variable of interest. It is designed to provide internally consistent estimates of the measured
concentration and fluxes, as well as histories that eliminate the influence of year-to-year variations in stream flow. This method was tested in the Chesapeake Bay Area and was designed with nutrients in mind but is likely to work well with other major ions and suspended sediment (Hirsch 2010). The EGRET package uses water quality sample data, daily stream flow data, and meta data from USGS web services or from user-supplied files. It then computes an estimate of concentration and flux for every day in the study period.

This method does not work with missing or provisional USGS data, which limited its use for the spring 2014 estimates as the USGS had not yet approved the data. In addition, it does not work with small, flashy systems that change by more than an order of magnitude in one day, such as Hungerford Brook. It also requires a minimum of 100 observations to run the WRTDS method. Thus, not all sites had enough observations for simulation. For the sites that met the data requirements, the EGRET WRTDS method was used. The original R script code was written by Peter Isles of the Rubenstein Eco-system Science Lab and then modified and adapted for other sites and analytes by Baxter Miatke.

4. Results
4.1 Defining Spring and Annual River Discharge

Discharge data were obtained from USGS gauge stations at 15-minute intervals to calculate the Missisquoi River water budget in cubic feet per year. The annual Missisquoi River discharge (Figure 7) confirms a higher volume of water at the mouth of the river near Swanton compared to that at the headwaters near North Troy. The spring 2014 discharge is also included for comparison to 2012 and 2013, although data are still considered provisional by the USGS. The spring snowmelt period varies by year (Figure 8). This research used a standard time frame from March 30th to May 1st for calculating loads. March 30th is the date when all 4 USGS gauges started recording data and May 1st is when “green” up occurred and snow cover was gone based on North American first leaf and first bloom lilac phenology data. (Schwartz 2003). This data set was located at Enosburg Falls in the Missisquoi River watershed that had an average leaf date of April 26th and average bloom date of May 22. This makes the time period of March 30th to May 1st and acceptable definition of spring snowmelt for all 4 gauges. This runoff time period is based on consistent seasonal metrics, but it should vary here depending on how the
late winter/spring meteorologically plays out each year. Each year and each site should have a different runoff time period, but it is simplified here to one uniform time period for easier spatial comparison. Figure 8 also shows the percentage of spring discharge compared to the entire year. The spring contribution to annual discharge has increased over the past three years and supports the argument that spring snowmelt and runoff significantly increases the amount of river discharge.

**Figure 7** - Missisquoi River discharge for 2012 and 2013

**Figure 8** - Missisquoi River discharge for Spring 2012-2014
4.2 Linear regressions

The linear regression models use all available data from the previous 2012 and 2013 RACC studies, as well as the spring 2014 data collected for this thesis research. Figure 9 shows an example of the linear regression models for TP, SRP, TN, and TSS at Swanton. Swanton data labeled by year is shown in Figure 10. Similar linear regression models for all 4 sites for TP, SRP, TN, and TSS and can be found in the Appendix. All linear regression models and associated $R^2$ values are summarized in Table 3. It is important to note that SRP did not always show a strong relationship with discharge like TP or TSS. However, the linear regression model was still used to estimate SRP loading. SRP is coupled more with TP and not related to discharge.

**Figure 9- Linear regressions for Swanton TP, SRP, TN, TSS**
Figure 10 - Linear regressions separated by 2012, 2013 and Spring 2014
<table>
<thead>
<tr>
<th>Regressions Used</th>
<th>TP Linear</th>
<th>R²</th>
<th>TN Linear</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swanton</td>
<td>y=2E-05x - 0.0079</td>
<td>0.5656</td>
<td>y = 4E-05x + 0.5877</td>
<td>0.241</td>
</tr>
<tr>
<td>Hungerford</td>
<td>y = 0.0016x + 0.0851</td>
<td>0.2716</td>
<td>y = 0.0023x + 2.277</td>
<td>0.033</td>
</tr>
<tr>
<td>East Berkshire</td>
<td>y = 5E-05x + 0.0018</td>
<td>0.3075</td>
<td>y = 0.0001x + 0.392</td>
<td>0.222</td>
</tr>
<tr>
<td>North Troy</td>
<td>y = 8E-05x + 0.0063</td>
<td>0.5121</td>
<td>y = 0.0002x + 0.3436</td>
<td>0.4133</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SRP Linear</td>
<td>R²</td>
<td>TSS Linear</td>
<td>R²</td>
</tr>
<tr>
<td>Swanton</td>
<td>y = 1E-07x + 0.0097</td>
<td>0.0014</td>
<td>y = 0.0198x - 36.195</td>
<td>0.6319</td>
</tr>
<tr>
<td>Hungerford</td>
<td>y = 0.0005x + 0.0269</td>
<td>0.3532</td>
<td>y = 0.6969x - 2.3168</td>
<td>0.4923</td>
</tr>
<tr>
<td>East Berkshire</td>
<td>y = 3E-06x + 0.004</td>
<td>0.0662</td>
<td>y = 0.5951x - 778.92</td>
<td>0.4409</td>
</tr>
<tr>
<td>North Troy</td>
<td>y = 7E-08x + 0.003</td>
<td>0.0003</td>
<td>y = 0.2446x - 87.241</td>
<td>0.2831</td>
</tr>
</tbody>
</table>
4.3 Load Estimations: 2012 vs. 2013 & Linear Regression vs. R Script WRTDS

The linear regression models were compared to the R Script WRTDS models to quantify the difference in load estimations. The linear regression model, although simple, was surprisingly close to the R Script WRTDS model. There was no gauge at Hungerford Brook in 2012, which explains the missing 2012 load estimations. The linear regression model also provides estimates where the R Script model falls short with small flashy rivers and sites without enough observations to meet the WRTDS n=100 constraint. The load estimations using both methods are calculated for 2012 and 2013 (Table 4 and 5, respectively) for comparison of the spatial nutrient relationships. In order to compare all sites across a timeframe when discharge was available, the period from 3/12/12-12/23/12 and from 3/23/13-10/23/13 was used. The percent difference is normalized to the output of the R script WRTDS model. A positive percent difference indicates the linear regression model is overestimating loadings, while a negative percent difference indicates it is underestimating, compared to the R script WRTDS model. These load estimates are plotted in Figures 12 and 13 for easier visualization of the two methods at each of the sites.

Table 5- Missisquoi River 2012 estimated loads (kg/yr) for linear regression model and R script model

<table>
<thead>
<tr>
<th>2012 Loads (kg/yr) (3/12/12-12/23/12)</th>
<th>TP Load Linear Regression</th>
<th>TP Load R Script</th>
<th>% Difference</th>
<th>TN Load Linear Regression</th>
<th>TN Load R Script</th>
<th>% Difference</th>
<th>TSS Load Linear Regression</th>
<th>TSS Load R Script</th>
<th>% Difference</th>
<th>SRP Load Linear Regression</th>
<th>SRP Load R Script</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swanton</td>
<td>8.61E+04</td>
<td>7.46E+04</td>
<td>14.29</td>
<td>8.90E+04</td>
<td>6.02</td>
<td>5.68E+07</td>
<td>6.31E+07</td>
<td>27.27</td>
<td>1.20E+04</td>
<td>1.90E+04</td>
<td></td>
</tr>
<tr>
<td>East Berkshire</td>
<td>7.19E+04</td>
<td>5.38E+04</td>
<td>28.77</td>
<td>3.87E+05</td>
<td>1.47</td>
<td>4.49E+08</td>
<td>1.47E+09</td>
<td>-106.59</td>
<td>6.75E+03</td>
<td>#N/A</td>
<td></td>
</tr>
<tr>
<td>North Troy</td>
<td>1.88E+04</td>
<td>2.60E+04</td>
<td>-32.40</td>
<td>1.14E+05</td>
<td>7.76</td>
<td>3.85E+07</td>
<td>2.89E+07</td>
<td>28.56</td>
<td>6.29E+02</td>
<td>#N/A</td>
<td></td>
</tr>
</tbody>
</table>

Table 4- Missisquoi River 2013 estimated loads (kg/yr) for linear regression and R script model

<table>
<thead>
<tr>
<th>2013 Loads (kg/yr) (3/23/13-10/23/13)</th>
<th>TP Load Linear Regression</th>
<th>TP Load R Script</th>
<th>% Difference</th>
<th>TN Load Linear Regression</th>
<th>TN Load R Script</th>
<th>% Difference</th>
<th>TSS Load Linear Regression</th>
<th>TSS Load R Script</th>
<th>% Difference</th>
<th>SRP Load Linear Regression</th>
<th>SRP Load R Script</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swanton</td>
<td>1.03E+05</td>
<td>9.64E+04</td>
<td>6.93</td>
<td>8.54E+05</td>
<td>11.24</td>
<td>7.66E+07</td>
<td>7.96E+07</td>
<td>3.85</td>
<td>1.10E+04</td>
<td>1.78E+04</td>
<td></td>
</tr>
<tr>
<td>Hungerford Brook</td>
<td>4.27E+03</td>
<td>#N/A</td>
<td>#N/A</td>
<td>3.25E+04</td>
<td>#N/A</td>
<td>1.38E+06</td>
<td>#N/A</td>
<td>#N/A</td>
<td>1.34E+03</td>
<td>#N/A</td>
<td></td>
</tr>
<tr>
<td>East Berkshire</td>
<td>8.71E+04</td>
<td>6.61E+04</td>
<td>27.49</td>
<td>3.97E+05</td>
<td>-1.37</td>
<td>2.05E+09</td>
<td>1.74E+09</td>
<td>-16.66</td>
<td>7.46E+03</td>
<td>#N/A</td>
<td></td>
</tr>
<tr>
<td>North Troy</td>
<td>2.29E+04</td>
<td>2.14E+04</td>
<td>6.65</td>
<td>1.26E+05</td>
<td>19.64</td>
<td>5.04E+07</td>
<td>3.68E+07</td>
<td>-31.27</td>
<td>6.48E+02</td>
<td>#N/A</td>
<td></td>
</tr>
</tbody>
</table>
Figure 12- 2012 TP, TN, and TSS flux estimates with linear regression vs. R script WRTDS methods over the Missisquoi River Basin
Figure 13 - 2013 TP, TN, and TSS flux estimates with linear regression vs. R script WRTDS methods over the Missisquoi River Basin
4.4 Loads Normalized by Land Use

The Missisquoi River Basin has many sub-catchment areas, which means the nutrient load may be higher simply due to a larger catchment area (all other parameters being equal). Therefore, each site-specific nutrient load estimate was normalized by the sub-catchment area (Table 6) so that we can assess the relative contribution of the 4 sites to watershed loading independent of catchment area and related differences in discharge. While Hungerford Brook had low loading estimates, it has higher nutrient load per square acre compared to the other sites in 2013 when data was available.

Table 6- 2012 & 2013 load estimations normalized by catchment area

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Swanton</td>
<td>0.16</td>
<td>0.19</td>
<td>1.63</td>
<td>1.57</td>
<td>104.19</td>
<td>140.56</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Hungerford Brook</td>
<td>#N/A</td>
<td>0.36</td>
<td>#N/A</td>
<td>2.74</td>
<td>#N/A</td>
<td>116.03</td>
<td>#N/A</td>
<td>0.11</td>
</tr>
<tr>
<td>East Berkshire</td>
<td>0.23</td>
<td>0.28</td>
<td>1.26</td>
<td>1.30</td>
<td>1466.58</td>
<td>6714.09</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>North Troy</td>
<td>0.21</td>
<td>0.27</td>
<td>11.23</td>
<td>1.48</td>
<td>452.76</td>
<td>593.03</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

4.5 Spring 2014 Load Estimates

Because the USGS spring 2014 discharge data were not approved at the time this document was written, the R script model could not be performed. However, the provisional discharge data were used in the linear regression modeling efforts. The estimates (Table 7) show that while the discharge values may still be provisional, they provide an important look into the amount of loading that occurs in the spring compared to the rest of the year.

Table 7- Spring 2014 load estimates for all Missisquoi River sites

<table>
<thead>
<tr>
<th>Spring 3/30/14-5/1/14</th>
<th>TP Load (kg/yr)</th>
<th>TN Load (kg/yr)</th>
<th>SRP Load (kg/yr)</th>
<th>TSS Load (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swanton</td>
<td>1.39E+05</td>
<td>6.53E+05</td>
<td>6.77E+03</td>
<td>1.19E+08</td>
</tr>
<tr>
<td>Hungerford</td>
<td>5.50E+03</td>
<td>3.14E+04</td>
<td>1.72E+03</td>
<td>1.97E+06</td>
</tr>
<tr>
<td>East Berkshire</td>
<td>1.44E+05</td>
<td>4.39E+05</td>
<td>1.02E+04</td>
<td>1.40E+09</td>
</tr>
<tr>
<td>North Troy</td>
<td>2.66E+04</td>
<td>1.02E+05</td>
<td>3.47E+02</td>
<td>6.97E+07</td>
</tr>
</tbody>
</table>
The same spring time period (3/30/14-5/1/14) was analyzed for 2012 and 2013 to determine how spring loading varies annually. Figures 14-16 show the total phosphorus, total nitrogen, and total suspended solids for the spring periods from 2012-2014.

**Figure 14- Spring 2012-2014 total phosphorus flux**

**Figure 15- Spring 2012-2014 total nitrogen flux**
5. Discussion

5.1 Nutrient Coupling to Streamflow

Total phosphorus concentrations appeared to be positively correlated with suspended solids concentrations (TSS) at each site. This relationship is well-documented, and is due to phosphorus association with primary or secondary minerals within the suspended sediment load. TSS also had a very strong relationship with discharge with an $R^2$ value of about 0.6. This indicates that TP and discharge are coupled. Flow and TP are most tightly correlated at Swanton, confirming that high discharge events deliver particularly high TP loads to Missisquoi Bay. However, soluble reactive phosphorus (SRP) does not always have a strong relationship with discharge. SRP instead is coupled with TP as part of the total phosphorus concentration (Figure 17). The SRP load was calculated, but not plotted on the bar graph of Figure 12 and 13 as the regression equation is not thought to be accurate. In the concentration and discharge plots (Appendix), SRP and discharge did not have a good linear regression fit. The SRP values are still reported in Tables 4 and 5 for comparative purposes. The total nitrogen (TN) concentrations also had a fairly good relationship with discharge as well at each site except Hungerford Brook. A future recommendation for obtaining better discharge relationships would be to separate low-flow and high-flow results using two different regression equations for each class of discharge. This may eliminate some of the outliers and disproportionate influence of
higher discharges on the data. In general, these data confirm that high flow events contribute disproportionately to nutrient loading within the Missisquoi River Basin, but that the particular relationship between discharge and load varies by both constituent and site/land cover.

![Swanton SRP vs. TP](image)

*Figure 17- Swanton 2012, Spring 2014 SRP vs. TP*

5.2 Spatial Load Comparisons

Nutrient loading (TP and TN) increases moving downstream in the Missisquoi River as expected due to progressively increasing in flow (Figure 12 & 13). The 2013 Hungerford Brook tributary data contributes a nutrient load of about 4% of the total nutrient load at Swanton to the Missisquoi system as well. This is significant for the small Hungerford drainage area that is only 2% of the total drainage area of Swanton’s. When normalized by catchment area, the 2013 Hungerford Brook data had the highest nutrient load per square acre compared to the other three sites (Table 6), indicating that Hungerford Brook is disproportionately important in the overall Missisquoi River nutrient loading budget. This also suggests that other small agricultural tributaries common throughout the Lake Champlain Basin, may also have disproportionately high impact on nutrient loads, the magnitude of which likely depends on agricultural practices within a tributary’s catchment. Significant increases in nutrient loading from North Troy to East Berkshire were also observed. This is most likely due to the fact that the river flows from a generally forested area to a primarily agricultural area here and the river geology changes from resistant bedrock to highly erodible lake sediments as well (Surficial Geology Map VT 2015).
Sediment loading was extremely high at East Berkshire and then dropped significantly at Swanton (Figure 12 &13). This means that during high flow events, there is much more sediment at East Berkshire than the other sites. The sediment load per square acre for East Berkshire was also the highest of all sites. (Table 6) This could mean there is more runoff, riverbank erosion, or effluent high in solids being added between North Troy and East Berkshire. The geology of the river also transitions from bedrock to lake sediments in this area explaining the particularly high erosive power of the river. The drop in TSS load between East Berkshire and Swanton can be explained by the high number of dams located along this portion of the river including the large Highgate Falls and Sheldon Falls hydroelectric facilities. These dams provide opportunities for sediments to settle out before reaching Swanton and Lake Champlain. The river gradient is also generally decreasing during this reach, which likely contributes to decreased suspended sediment loads. Spatial load comparisons are powerful for understanding how rivers change through different land uses and geology on a large watershed scale.

5.3 Load Comparisons 2012 vs. 2013

When comparing the nutrient and sediment loads annually between 2012 and 2013, there are many similarities. Each site and nutrient had similar trends and orders of magnitude between both years. The 2012 annual discharge was slightly higher than 2013. This could be due to effects from Superstorm Sandy that hit the east coast in October 2012. It was also a generally dry summer and wet fall in 2012, which produced optimal conditions for high sediment and nutrient concentrations when storms did finally occur through flushing of sediment/dry soils and nutrients that had accumulated in the watershed over the summer. A higher discharge year should produce higher load estimates than lower discharge years, but the timing of delivery of water and loads in these two years varied. The concentrations show the nutrient and TSS concentrations were generally higher in 2012 than 2013, but the load estimates were opposite with lower annual fluxes in 2012 than 2013. This demonstrates that an extreme storm event can cause high concentrations in a short period of time, but still have low annual loads compared to the rest of the year.
5.4 Spring Runoff Analysis

The spring 2014 data provided a unique look into an understudied time of the year in the Missisquoi River and regionally. The discharge for the spring runoff period shows that about 30% of the annual discharge comes from just this March-May spring time period. The 2014 spring nutrient load seemed high compared to annual loads from 2012 and 2013, so the same spring time period was used to analyze the 2012 and 2013 data as well. Since the rest of the 2014 data was not available, the spring 2013 TP flux was compared to the 2013 annual flux to determine that the spring nutrient load was about 30% of the annual TP load. This is a significant portion of the nutrient load and shows how the spring runoff delivers significant nutrient loads that can contribute to the generation of HAB’s later in the summer months, particularly those associated with sediments that are likely to remain in the Bay. There is also dramatic variability in spring flow and loading in just the three year period analyzed here, confirming that spring snowmelt can cause dramatic variability in both the timing and magnitude of nutrient and sediment loadings each year.

5.5 Literature Comparison

No literature was found with a specific spring nutrient loading estimates for Lake Champlain or Vermont; but there has been a lot of research on nutrient loading to Lake Champlain and in general during the summer and fall. Smeltzer et. al. (2012) and Medalie et. al. (2013) show work similar to this research at different rivers and streams in the Lake Champlain Basin focusing on phosphorus and nitrogen. These data sets do not include rigorous spring data points. The 2012 and 2013 TP annual flux from this research for Swanton was converted from kilograms per year to metric tons per year for easy comparison to published data (Table 8).
Smeltzer (2012) showed that 24.1% of the total phosphorus load into Lake Champlain comes from the Missisquoi watershed. Smeltzer’s phosphorus load estimates used regression relationships to predict concentrations and calculate daily loads over the course of the year. Annual TP flux estimates from 1991 to 2008 for the Missisquoi River had a range of 108 to 211 mt/yr. The linear regression TP estimates in this work (Table 8) fall below the Smeltzer (2012) estimates. This may be the result of using a single linear regression model. Creating separate regression models for low flow and high flow might increase the annual flux estimates and align closer to the estimates of Smeltzer (2012). Medalie (2013) also generated flux estimates for total phosphorus and total nitrogen in 18 Lake Champlain tributaries, but used the WRTDS model. The WRTDS method uses average daily discharge as opposed to the 15-minute discharge sampling of the regression methodology. TP estimates of Medalie (2013) ranged from 85 to 338 mt/yr. The 2012 WRTDS analysis falls below that range at 75 mt/yr, but is in that range for the 2013 at 96 mt/yr. The WRTDS estimates are closer to published of by Medalie (2013) than the regression estimates are to those of Smeltzer (2012). This is predictable considering that we used the same WRTDS model as Medalie (2013) for load estimation, whereas we used a different linear regression approach than that employed by Smeltzer 2012. However, this research comprises only two years of data and only one set of spring samples, which shows the need for further monitoring. Both methods suggest that 2012 and 2013 were on low end of recent historical loads of TP for the Missisquoi River.

### Table 8- Swanton TP Annual Flux (mt/yr)

<table>
<thead>
<tr>
<th></th>
<th>TP Load Linear Regression (mt/yr)</th>
<th>TP Load R Script (mt/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swanton 2012</td>
<td>86.11</td>
<td>74.62</td>
</tr>
<tr>
<td>Swanton 2013</td>
<td>103.36</td>
<td>96.43</td>
</tr>
</tbody>
</table>
6.0 Conclusion

The spring snowmelt and runoff period play a critical role in the Missisquoi River nutrient loading. The springtime river discharge is a large percentage of the annual river discharge for 2012 and 2013. The spring snowmelt also varies dramatically on an inter-annual basis. This makes defining the same snowmelt period for all sites difficult, but using Lilac leaf and bloom data coupled to the onset of USGS gage monitoring a good way of defining the snowmelt period for this watershed. The different methods for calculating nutrient loads have both advantages and drawbacks. The linear regression model and WRTDS R Script model provide similar estimates, but the linear regression model tended to have slightly higher estimates. The linear regression model is good for comparative purposes, but the WRTDS model results better match the WRTDS results of Medalie (2013). The first two years of RACC watershed monitoring (2012 and 2013) were on the low end of annual loading from the MR watershed based on the historical monitoring/load estimates. However, it looks like the annual load for 2014 will be significantly higher based of the spring 2014 estimates. Regardless of nutrient load calculation method, the spring snowmelt period is a critical time period for nutrient and sediment loading. The spring total phosphorus and nitrogen loading was over 1/3 of the annual load estimates for 2013. The sediment spring loads followed a similar trend to phosphorus and nitrogen with the exception at East Berkshire due to river geology and influence of dams. Load estimates will vary greatly based on the snowmelt period shown by the higher estimates for spring 2014.

This research can be applied to other watersheds that VT-EPSCoR and RACC are working on now. This research shows the need for more monitoring during spring snowmelt and more general work across an entire watershed. The four sites and addition of the spring data provided a better spatial and seasonal analysis of nutrient loading trends for the Missisquoi River watershed. This data can be used to further inform land management practices seasonally and spatially. The land use and the loadings normalized by land use might be used to make targeted effective change in the watershed and help lower nutrient loading to Lake Champlain. This research provides an insight to nutrient and sediment loading seasonally and spatially in
order to help limit excessive nutrient loading during spring runoff and reduce HAB’s in Lake Champlain during the summer.
References


Rabah Mazouz, Application of redundancy analysis to hydroclimatology: A case study of spring heavy floods in southern Québec (Canada), Journal of Hydrology, Volume 496, 24 July 2013, Pages 187-194


Dani Newcomb, “Links between geomorphic condition, water quality, and phosphorus loading in Hungerford Brook, Vermont”, Thesis presented to Faculty of the Graduate College of The University of Vermont, October 2007.


Weather Underground, “Burlington International Airport”, 2014
Appendix

Swanton TN  \( y = 4.6 - 0.05x + 0.5877 \)  \( R^2 = 0.241 \)

Hungerford TN  \( y = 0.0023x + 2.277 \)  \( R^2 = 0.033 \)

East Berkshire TN  \( y = 0.0003x + 0.392 \)  \( R^2 = 0.222 \)

North Troy TN  \( y = 0.0003x + 0.3436 \)  \( R^2 = 0.4133 \)